EFFECT OF DEFECT WIDTH UPON BURST CAPACITY OF COMPOSITE REPAIRED PIPE

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Dalam tahun-tahun kebelakangan ini, penggunaan komposit polimer diperkuat gentian (FRP) dalam pembaikan saluran paip adalah salah satu sistem pemulihan saluran paip yang lebih digemari dalam industri saluran paip. Walau bagaimanapun, beberapa isu tentang kaedah pembaikan ini tidak difahami sepenuhnya oleh industri. Kesan geometri kecacatan mempengaruhi kecekapan paip yang dibaiki dengan komposit adalah salah satu isu yang menjadi perhatian industri. Kods dan piawaian untuk reka bentuk saluran paip telah dibangunkan dengan memberi tumpuan kepada kedalaman kecacatan dan mengabaikan geometri kecacatan lain seperti panjang kecacatan dan lebar kecacatan dalam memperbaiki saluran paip yang rosak. Kajian lepas menunjukkan bahawa kod dan piawaian ini dianggap konservatif dan terdapat ruang untuk pengoptimuman. Kajian terdahulu menyatakan bahawa geometri kecacatan terutamanya lebar kecacatan tidak boleh diabaikan dalam menilai dan merekabentuk sistem pembaikan paip. Ini juga terbukti dalam beberapa kod penilaian yang menggunakan geometri kecacatan sebagai salah satu parameter untuk menilai keadaan paip secara berkesan. Oleh itu, tekanan letus dari saluran paip yang rosak tertakluk kepada pelbagai lebar kecacatan ditentukan melalui kajian ini untuk menilai kesan lebar kecacatan kepada kapasiti letus paip diperbaiki komposit. Analisis unsur terhingga digunakan untuk menentukan kapasiti letus paip diperbaiki komposit dengan bentuk kecacatan segi empat tepat. Terdapat tiga lebar yang berlainan (*D*, *½D* dan *2D*, yang mana *D* ialah diameter paip) dipilih untuk dianalisa tanpa perubahan pada panjang dan kedalaman kecacatan. Model asas paip yang diperbaiki oleh komposit telah dibuat, disahkan dan diubahsuai dengan pelbagai lebar kecacatan yang disebut sebelum ini. Hasil kajian menunjukkan bahawa tekanan letus bagi tiga model berbeza-beza dengan peratusan 12.51% antara tekanan letus maksimum dan tekanan letus minimum. Gambar rajah plot kontur tekanan yang didapati daripada analisis unsur terhingga juga menunjukkan bahawa kawasan kepekatan tekanan tertinggi (557.7MPa) sekitar rantau kecacatan semakin besar apabila lebar kecacatan semakin luas dimana kawasan kecacatan juga semakin besar. Dengan ini, paip yang diperbaiki oleh komposit akan mengalami kegagalan dalm tekanan yang lebih rendah apabila kecacatan semakin meluas. Berdasarkan dapatan ini, lebar kecacatan terbuktikan akan mempengaruhi kepasiti letus paip yang diperbaiki oleh komposit.

ABSTRACT

In recent years, application of FRP composite in repairing steel pipeline is the most preferable pipeline rehabilitation system used in the pipeline industry. However, some issues about this repair method are not fully understood by the industry. Effect of defect geometry toward the efficiency of composite repair pipe is one of the issues that concerned by the industry. Design codes and standards of pipeline repair method have been developed mainly focus on defect depth and neglect other defect geometries such as defect length and defect width in repairing damaged pipeline. Past researches show that these codes and standard are considered conservative and there are rooms for optimization. Previous studies states that defect geometry especially defect width should not be ignored in evaluating and designing pipe repair system. This is also proven in some of the assessment codes that used defect geometry as one of the parameter to effectively assess the condition of pipe. Therefore, the burst pressure of the defective pipeline subjected to various defect widths is determined through this study in order to evaluate the effect of defect width upon the burst capacity of composite repaired pipeline. Finite element analysis was used to determine the burst capacity of the composite repaired pipe with rectangular shape of defect. There are three different widths (*D*, *½D* and *2D*, where *D* is the pipe diameter) were selected for analysis with no changes on defect length and depth. The base model of composite repaired pipe was created, validated and modified with the various defect widths that mentioned before. The result shows that burst pressure for three different models vary with a percentage of 12.51% between the maximum burst pressure and minimum burst pressure. The stress contour plot diagrams that extracted from the finite element analysis also shows that the area of highest stress (557.7MPa) concentration around defect region is getting bigger when the defect width is getting wider with the defect area getting larger. With this, the composite repaired pipe tends to fail at lower pressure when the defect is getting wider. Based on the results, the defect width is proven to affect the burst capacity of composite repaired pipe.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

σ_{H}	Hoop stress of pipe at failure
$\bar{\sigma}$	Material flow stress
$\sigma_{m(YS)}$	Specified Minimum Yield Stress (SMYS) of the material
σ_A	Longitudinal compressive stress due longitudinal force
σ_B	Longitudinal compressive stress due to bending moment
σ_L	Combined nominal longitudinal stress
γ_d	Partial safety factor for corrosion depth.
γ_m	Partial safety factor for corrosion model prediction
ε_c	Allowable circumferential strain of the composite
ε_d	Factor for define fractile value of corrosion depth
ξ	Usage factor for longitudinal stress
θ	Ratio of circumferential length of corroded region to the nominal circumference of the pipe
A_r	Circumferential area reduction factor
c	Circumferential length of corroded region
d	Depth of defect
D	Outer diameter of pipe
E_c	Tensile modulus for the composite laminate in circumferential direction
E_s	Tensile modulus for substrate material
f_u	Tensile strength to be used in design
F	Safety factor
F_a	Total axial tensile loads due to pressure, bending and axial thrust
F_{eq}	Equivalent axial load
F_x	External longitudinal force
H_1	Factor to account for compressive longitudinal stresses
L	Maximum length of defect
M	Folias factor
M_y	External bending moment
P	Internal design pressure
P_{corr}	Maximum allowable operating pressure
$P_{coor,comp}$	Maximum allowable pressure in corroded pipe

P_{live}	Pipe internal pressure during repair
P_s	Maximum Allowable Operating Pressure (MAOP)
s	Specific Minimum Yield Strength (SMYS)
t	Remaining wall thickness of corroded pipe
t_{repair}	Design repair laminate thickness
t_s	Minimum remaining wall thickness of the composite

LIST OF ABBREVIATIONS

ASME	American Society of Mechanical Engineers
DGEBA	Diglycidyl Ether of Bisphenol-A
DNV	Det Norske Veritas
FE	Finite Element
FRP	Fibre Reinforced Polymer
MAOP	Maximum Allowable Operating Pressure
SMTS	Specified Minimum Tensile Strength

CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

Steel pipelines have been used as a basis element to transport oil and natural gas in large quantities over a long distance. This can be seen in the pipeline industry performance report, which launched by the Canadian Energy Pipeline Association (CEPA). CEPA stated that 2.9 billion dollars were spent in maintaining and monitoring pipeline systems over 2013 and 2014 (Canadian Energy Pipeline Association., 2015). Pipelines are considered as the most effective and economically reliable transportation mode for natural gas and oil as it can resist high pressure of fluid and gases (Ehsani, 2015). However, deterioration will happen on pipeline when oil and natural gas pipelines are exposed to the critical environment such as underground or fully submerged in seawater. Besides that, other factors such as material and construction defects, mechanical damage from construction, corrosion, creep and so on (Kishawy and Gabbar, 2010) will also cause deterioration on pipeline. Hence, reduction of bearing capacity of pipelines, wall thinning or cracks might happen and leakage of oil or gas might be the results of these deteriorations. This condition will become a threat to human health and pollution in the environment. Besides that, a corroded pipeline will lead to high expenses on repairing defective pipeline and cause inconvenience to the industry as the strength of pipeline will be reduced as well as service life of the pipeline.

The negative effects of deterioration on the pipeline can be seen in accidents such as explosion and pollution to environment that happened in recent years. This can be proven by the accident happened in Marshall, Michigan in 2010 when the ruptured pipeline released 4200m^3 of crude oil to the surrounding wetland and Kalamazoo River (National Transportation Safety Board, 2010). Besides the negative effect of oil spill towards the environment, clean-up efforts in this accident needed 767 million dollars to complete even though there were no fatalities reported. An explosion of the crude oil pipeline in Qingdao in eastern China killed 62 people and injured 136 people in 2013. This explosion caused 124.9 million dollars of direct economic loss and the oil spill had caused pollution to the about 3000 m^2 of sea water. Worker error on repairing the corrode pipeline as non-explosion proof hydraulic hammer was used and lighted sparks that caused blast in the pipeline (Aizhu, 2013). With all these accidents happened and pipeline that in service failed prematurely, the predominant techniques to rehabilitate the damaged pipeline due corrosion and metal loss is important to be available in the industry.

There are numerous repair methods available for the corroded pipeline of onshore or offshore. For instance, replacement of a new pipe for the entire damaged pipe or only for the particular section of the damaged area. Welding steel sleeve to the existing pipe also a technique to repair pipeline because the steel sleeve will act as a new pipe to the pipeline when defect fails and it will maintain the flow of resource in the pipe and thus the pipe system can operate as usual. Although these techniques are effective, but time-consuming, costly and dangerous if using welding work near the volatile substances inside the pipe (Melander and Österberg, 2016). In recent years, many pipeline operators prefer to use Fibre Reinforced Polymer (FRP) repair system to restore the strength of damaged pipes. The corroded defect area on the transmission pipeline will be strengthening by wrapping a composite sleeve bonded by epoxy grout to the pipe. Furthermore, the FRP composite offers many advantages such as corrosion resistance, lightweight, dimensional stability and high strength (Saeed, 2015). Besides the advantages offer by this method, there are some issue about the behaviour of FRP composite polymer occur and not fully study by the industry such as complexity of surface preparation for repairing, de-bonding between defective pipe with composite polymer, performance and contribution of the infill material, effect of defect geometry and conservativeness in existing design codes (Lim et al., 2015). Amongst the issues, FRP composite repair system that focused in this research aims to study the effect of defect width towards burst capacity of a composite repaired pipe.

1.2 Research Problem

Nowadays, deteriorations caused by corrosion towards pipelines have been the greatest concern of the oil and natural industry to maintain the pipeline integrity. This is stated by NACE International, where corrosion problem was estimated to cost 2.5 trillion dollars annually worldwide, which is 3 to 4% of Gross Domestic Product of industrialized countries (Gerhardus et al., 2016). Besides pipe wall thinning due to corrosion, other factors such as material degradation and cracks that cause a defect on the pipe are also the main concern of the pipeline operators. The condition of pipeline contains corrosion defect will have the negative impact of high stress concentration at the deepest point of flaw area, the pipeline may burst at that point if the operating pressure in the pipe has reached its maximum burst pressure (Fekete and Varga, 2011). However, it is not necessary to repair or replace the whole pipe when there are some minor defects occur on the pipe. Evaluation of the pipeline condition will be conducted with assessment codes and standard to determine whether the pipeline is still safe to operate. If repairs are necessary, pipeline operators can choose the most suitable repair system based on the condition of the pipeline (Lim et al., 2015).

Fibre reinforced polymer composite repair system is one of the repair technique that is widely used by oil and natural gas industry. It is used with the recent development of design codes and standards in recovering the damaged pipeline. Standards such as ASME PCC-2 and ISO 24817 were developed for the industry in designing the composite repair system to ensure the safety and effectiveness of the repaired pipeline (Alexander and Worth, 2010). These standards are known to be conservative as they implemented overdesign repairing method due to safety factory and premature replacement which is costly (Duell et al., 2008). Remaining pipe wall thickness and outer diameter of pipe are the parameters that considered in these codes standards but the defect geometry is neglected. In contrast, some of the assessment codes and standards considered defect geometry as one of the parameter to evaluate the condition of corrosion defects on the pipe by determining the remaining strength of the corroded area. Besides that, many modifications have applied on some of the original equations of assessment codes and standards to reduce conservativeness. For example, code ASME B31Gmod was modified from the code ASME B31G, which was developed by the American Society of Mechanical Engineers and was adopted as the US national standard (American Society

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